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Magnetohydrodynamic Electromagnetic Pulse Assessment of the Continental U.S. Electric Grid: Geomagnetically Induced Current and Transformer Thermal Analysis

Primary Audience: Asset Owners and Operators of the United States Bulk-Power System

Secondary Audience: Regulators, State and Federal Entities

Key Research Question

This study was performed to determine the potential for a significant number (hundreds) of bulk-power transformers to experience thermal damage caused by the geomagnetically-induced current (GIC) flows generated by a single high-altitude nuclear burst over the Continental United States (CONUS). The research sought to reconcile opposing conclusions presented in earlier research performed by Oak Ridge National Laboratories (ORNL) in the mid-late 1980's and Metatech in late 2000's related to the effects of magnetohydrodynamic electromagnetic pulse(MHD-EMP, E3) on bulk-power system transformers.

Research Overview

This research evaluated the potential impacts of E3 on bulk-power system transformers. The fundamental approach to this study was similar to that adopted by the North American Electric Reliability Corporation (NERC) to assess the potential impacts of severe geomagnetic disturbance (GMD) events on bulk-power transformers. First, the electric field environment necessary for calculating GIC flows was identified and a dc model of the interconnection-wide system was assembled. For this study, a publicly available MHD-EMP (E3) environment along with a model of the United States bulk electric system was used to calculate the GIC flows in the transmission system that would result from a single, high-altitude detonation over the CONUS. GIC calculations were then performed assuming 11 different target locations. The resulting time-series GIC flows were then used to compute the time-series hotspot temperature of each bulk-power system transformer included in the interconnection-wide assessment. The maximum instantaneous hotspot temperatures were then evaluated against conservative temperature limits that were based on an assumed condition-based GIC susceptibility category of the entire transformer fleet. The number of transformers that were identified as exceeding the specified temperature limits were then combined with the probabilities of a given transformer being in one of the three specified categories to estimate the number of bulk-power transformers to be at potential risk of thermal damage. Additionally, the potential for thermal damage caused by circulating harmonic currents in the tertiary windings of large autotransformers was also evaluated.

Key Findings

- Although a significant number of transformers (hundreds to thousands) could experience GIC flows greater than or equal to 75 amps/phase (screening criteria adopted from NERC TPL-007-1), only a small number (3 to 14 depending on the target location evaluated) of these transformers were found to be at potential risk of thermal damage. In addition, the at-risk transformers were found to be geographically dispersed.
- Assessment results also indicate that damaging levels of tertiary winding heating resulting from the flow of harmonic currents generated by the resulting GIC flows are unlikely to occur.

Why This Matters

Results of prior assessments performed to determine the impacts of E3 on bulk-power transformers range from transformer damage from E3 is unlikely[1] to up to 100 transformers could be at potential risk of thermal damage[2]. The results of this study provide a strong technical basis for reconciling these opposing conclusions.

[1] "Impacts of a Nominal Nuclear Electromagnetic Pulse on Electric Power Systems – Phase III – Final Report," *Oak Ridge National Laboratory (ORNL),* ORNL/Sub-83/43374/2/April 1991.

[2] "Meta-R-321, The Late-Time (E3) High-Altitude Electromagnetic Pulse (HEMP) and Its Impact on the U.S. Power Grid," *Metatech Corporation,* January 2010, https://www.ferc.gov/industries/electric/indus-act/reliability/cybersecurity/ferc_executive_summary.pdf.

How to Apply Results

The results of this study are in agreement with earlier work performed by ORNL which indicate that the failure of a large number (hundreds) of bulk-power transformers from E3 is unlikely. The assessment results can be used to help quantify the overall risk of E3 impacting the bulk-power system as a whole (interconnection-level assessment), but should not be interpreted to indicate E3 will not affect bulk-power reliability since the potential for widespread outages due to voltage collapse or the synergistic effects of E1, E2 and E3 are still being investigated. Additionally, because of the number of conservative assumptions that were required due to the lack of asset specific data, the results should not be used to inform investment decisions at individual utilities.

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